SHORT COMMUNICATION

Response of soil carbon and nitrogen to transplanted alfalfa in North Dakota rangeland

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Liebig, M. A., Hendrickson, J. R. and Berdahl, J. D. 2010. **Response of soil carbon and nitrogen to transplanted alfalfa in North Dakota rangeland**. Can. J. Soil Sci. **90**: 523–526. Incorporation of alfalfa (*Medicago* spp.) into rangelands can increase forage production and quality and may improve the soil resource. A study was conducted to quantify the effects of alfalfa transplanted into native rangeland on soil organic carbon (SOC) and total nitrogen (TN). Results from this study suggest both grazing- and hay-type alfalfa can increase stocks of soil C and N in native rangeland. However, concurrent increases in SOC and TN in a non-alfalfa control treatment underscore the importance of applying caution when interpreting results.

Key words: Northern Great Plains, carbon sequestration, *Medicago falcata*, *Medicago sativa*

Liebig, M. A., Hendrickson, J. R. et Berdahl, J. D. 2010. **Réaction de la teneur en carbone et en azote du sol à la plantation de luzerne sur les grands parcours du Dakota Nord**. Can. J. Soil Sci. **90**: 523–526. Intégrer la luzerne (*Medicago* spp.) aux grands parcours pourrait accroître la production et la qualité de fourrage ainsi qu'améliorer la qualité du sol. Les auteurs ont entrepris une étude afin de quantifier les effets de la luzerne semée dans les parcours naturels sur la teneur en carbone organique du sol et sur l'azote total. Les résultats indiquent que la luzerne utilisée pour la paissance et la production de foin peut accroître les réserves de C et de N dans le sol des grands parcours naturels. Néanmoins, une hausse de la concentration de carbone organique et de l'azote total survenue parallèlement dans le sol d'une parcelle témoin sans luzerne souligne qu'il faut faire preuve de prudence lorsqu'on interprète les résultats.

Mots clés: Grandes plaines du nord, séquestration du carbone, *Medicago falcata*, *Medicago sativa*

The quantity and quality of forage produced on native rangeland directly impacts livestock production, which in turn contributes significantly to rural economies. Consequently, management interventions that increase forage production and quality are of significant interest to livestock producers. In this regard, alfalfa (*Medicago* spp.) interseeded into native rangeland has been documented to improve the quantity and quality of forage for livestock production within the Northern Great Plains of North America (Berdahl et al. 1989).

Alfalfa is well-known to increase soil nitrogen (Kelner and Vessey 1995) and soil organic carbon (SOC) (Angers 1992), as well as to improve soil aggregate stability in extended cropping system rotations or permanent pasture (Raimbault and Vyn 1991). Information regarding soil responses to interseeded alfalfa in rangeland, however, is scarce. Mortenson et al. (2004, 2005) evaluated effects of yellow-flowered alfalfa (*M. sativa* spp. *falcata*) interseeded in a mixed-grass rangeland on carbon sequestration, N fixation, and forage production. Their work, conducted on the Smith Ranch in northwestern South Dakota, found rangeland interseeded with alfalfa in 1965, 1987, and 1998 to exhibit increases in SOC at 0 to 1 m of 11.8 Mg C ha^{-1} (17%), 9.1 Mg C ha^{-1} (8%), and 4.7 Mg C ha^{-1} (4%), respectively, relative to native rangeland without alfalfa.

In 2001, Hendrickson et al. (2008) initiated a study to investigate the effects of defoliation timing on alfalfa transplanted into a mixed-grass native rangeland near Mandan, North Dakota. The study provided the opportunity to extend work done by Mortenson et al. (2004) regarding interseeded alfalfa effects on SOC and total N (TN), but in a more controlled environment. Accordingly, the objectives of our research were to quantify the effects of alfalfa transplanted into native rangeland on SOC and TN.

Methods

The experimental site was located at the USDA-ARS Northern Great Plains Research Laboratory southern research station approximately 5 km south of Mandan, North Dakota, USA (lat. 46°46′35″N, long. 100°54′20″W). The site was on gently rolling uplands (0 to 3% slope) with a silty loess mantle overlying Wisconsin age till.

Abbreviations: **SOC**, soil organic carbon; **TN**, total nitrogen

Predominant soil at the study site was a Temvik silt loam (Fine-silty, mixed, superactive, frigid Typic Haplustoll) (Soil Survey Staff 2009), which is similar to a Dark Brown Chernozem (Soil Classification Working Group 1998). A baseline evaluation of near-surface soil attributes (0 to 0.4 m) prior to initiating the study found clay content to range from 216 to 276 g kg^{-1}, low soil bulk densities (0.97 to 1.20 Mg m^{-3}), slightly acid to neutral soil pH, and cumulative SOC and TN of 81 Mg C ha^{-1} and 7.4 Mg N ha^{-1}, respectively.

Three alfalfa cultivars transplanted into rangeland and a native vegetation control were evaluated for their effects on SOC and TN in conjunction with an alfalfa defoliation study as described by Hendrickson et al. (2008). Vegetation composition at the site included a mix of native grass species (e.g., western wheatgrass [*Pascopyrum smithii* (Rydb.) A. Löve], green needlegrass [*Nassella viridula* (Trin.) Barkworth], needleandthread [*Hesperostipa comata* (Trin. & Rupr.) Barkworth ssp. *comata*], and blue grama [*Bouteloua gracilis* (Willd. ex Kunth) Lag. ex Griffiths]) and native forbs (e.g., prairie coneflower [*Ratibida columnifera* (Nutt.) Woot. & Standl.], scurfpea [*Psoralidium lanceolatum* (Pursh) Rydb] and goldenrod species (*Solidago* L. spp.)). Alfalfa cultivars evaluated included two grazing-type alfalfas (Anik and Yellowhead) and one hay-type alfalfa (Vernal; *M. sativa* spp. *varia*). Alfalfa plants were grown in conetainers in a greenhouse and then transplanted into a mixed-grass native rangeland site on 2001 Jul. 05. The protocol for transplanting involved inserting a metal rod (0.04 m diameter; 0.205 m length) into the soil to create a hole for each alfalfa plant. Alfalfa plants were then placed in the holes on 2.4-m centers, with each plant occupying a 0.5-m^2 plot. In addition to the alfalfa plots, 15 native vegetation plots without alfalfa were included as controls. Transplanting holes were not made within the control plots. Of the alfalfa plots used for defoliation treatments by Hendrickson et al. (2008), only plots that were unclipped were included in this study, resulting in five plots for each alfalfa cultivar and the controls, which were considered replicates. This treatment structure utilized a completely randomized block design, with unclipped alfalfa and controls as treatments of interest. This design differed from that used by Hendrickson et al. (2008), where a completely randomized design with a two-level factorial arrangement of treatments was employed to evaluate clipping effects on above-ground biomass production.

On 2001 Sep. 27 and again on 2005 Oct. 11, soil samples were collected from the alfalfa and control plots as described above. In 2001, two soil cores were collected in an east-west orientation approximately 0.15 m from the center of each plot (designated by an alfalfa crown). In 2005, a north-south orientation was employed using the same distance from the plot center. At each sampling point, soil samples were collected to 0.4-m in depth increments of 0 to 0.1, 0.1 to 0.2, 0.2 to 0.3, and 0.3 to 0.4 m using a 0.031-m (i.d.) step-down probe. Duplicate soil cores from each treatment were composited by depth. Each sample was saved in a double-lined plastic bag and placed in cold storage at 5°C until processing. Holes created by sampling were back-filled with surface soil (upper 0.4 m) collected from an adjacent paddock with the same soil type.

Soil samples were dried at 35°C for 3 to 4 d and ground by hand to pass a 2.0-mm sieve. Identifiable plant material (>2.0 mm) was removed during sieving. Air-dry water content was determined for each sample using a 12- to 15-g subsample by measuring the difference in mass before and after drying at 105°C for 24 h. Samples were analyzed for total soil C and N by dry combustion on soil ground to pass a 0.106-mm sieve (Nelson and Sommers 1996). Soil organic C was considered the same as total C, as carbonates were not present in the depths sampled. Gravimetric data were converted to a volumetric basis for each sampling depth using field-measured soil bulk density, which was determined using the oven-dry weight and known volume of the composited samples (Blake and Hartge 1986). All data were expressed on an oven-dry basis.

To eliminate effects of sampling depth and soil bulk density on SOC and TN, data from the 2001 and 2005 samplings were recalculated on an equivalent mass basis assuming soil profile mass of 3000 Mg ha^{-1} for each treatment following the method of Ellert and Bettany (1995). These data were used to determine changes in SOC and TN stocks between 2001 and 2005. Data were analyzed using PROC MIXED in SAS software (Littell et al. 1996) with vegetation treatment and replicates considered fixed and random effects, respectively. A significance criterion of $P \leq 0.10$ was used to document differences among means.

Findings

The effects of transplanted alfalfa on soil bulk density, SOC, and TN were modest 4 yr after treatment establishment (Table 1). Soil bulk density did not differ among treatments at any depth, and the range of observed values (0.94 to 1.21 Mg m^{-3}) was similar to that during the initial sampling. Soil organic C and TN differed only among treatments at 0 to 0.1 m, where Vernal and Anik possessed greater SOC and TN than the non-alfalfa control. Additionally, SOC and TN under Yellowhead were not different from the other treatments at 0 to 0.1 m.

Stocks of SOC within the surface 3000 Mg ha^{-1} of soil increased significantly between 2001 and 2005 under Anik and Vernal, but not the other treatments (Fig. 1a). Numerically, increases in SOC under Anik and Vernal were substantial (4.1 and 4.0 Mg C ha^{-1}, respectively). Though not statistically significant, the other treatments observed notable numerical increases in SOC between 2001 and 2005 (e.g., Yellowhead, 2.9 Mg C ha^{-1}; non-alfalfa control, 1.5 Mg C ha^{-1}). The numerical increase in SOC within the non-alfalfa control is particularly important to acknowledge, as it may reflect the

Table 1. Soil bulk density, soil organic C, and total N within each treatment 4 yr after transplanting alfalfa into rangeland

	Treatment				
Depth (m)	Control	Anik	Yellowhead	Vernal	*P* value
			Soil bulk density ($Mg\ m^{-3}$)		
0 to 0.1	0.97 (0.03)[z]	0.99 (0.02)	0.94 (0.02)	0.98 (0.03)	0.5913
0.1 to 0.2	1.09 (0.02)	1.18 (0.01)	1.14 (0.01)	1.17 (0.04)	0.1321
0.2 to 0.3	1.08 (0.02)	1.11 (0.03)	1.08 (0.03)	1.09 (0.02)	0.7475
0.3 to 0.4	1.18 (0.03)	1.17 (0.04)	1.21 (0.03)	1.18 (0.05)	0.8581
			Soil organic C ($Mg\ C\ ha^{-1}$)		
0 to 0.1	33.5 (0.6)	35.6 (0.7)	34.5 (0.5)	35.3 (0.7)	0.0448
0.1 to 0.2	22.9 (2.5)	19.9 (0.5)	21.7 (1.2)	20.6 (0.9)	0.1751
0.2 to 0.3	15.5 (0.3)	15.0 (0.8)	14.9 (0.9)	15.0 (0.9)	0.9271
0.3 to 0.4	14.6 (0.9)	13.6 (0.7)	13.9 (1.1)	14.3 (0.4)	0.7623
			Total N ($Mg\ N\ ha^{-1}$)		
0 to 0.1	2.8 (<0.1)	3.1 (0.1)	2.9 (0.1)	3.0 (<0.1)	0.0102
0.1 to 0.2	2.1 (0.2)	1.9 (<0.1)	2.1 (0.1)	2.0 (0.1)	0.2765
0.2 to 0.3	1.5 (<0.1)	1.5 (0.1)	1.5 (0.1)	1.5 (0.1)	0.9341
0.3 to 0.4	1.5 (0.1)	1.4 (0.1)	1.4 (0.1)	1.5 (<0.1)	0.7466

[z]Values in parentheses represent standard errors of the mean.

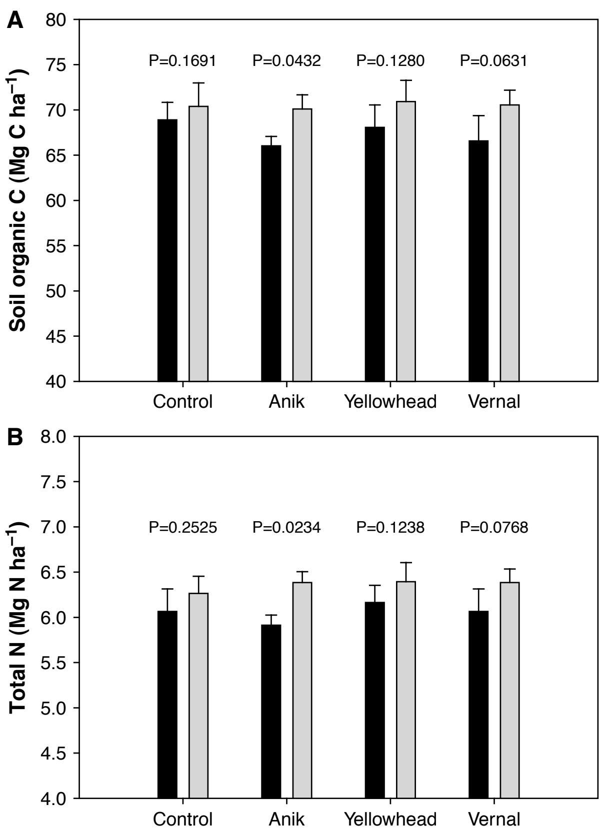

Fig. 1. Soil organic C (A) and total N (B) stocks in 2001 (black bar) and 2005 (grey bar) for treatments evaluated in study. Error bars represent standard error of the mean. *P* values for mean comparisons of sampling time within each treatment are placed above paired bars.

contribution of native vegetation to SOC stock change during the evaluation period.

Similar to SOC, TN stocks under Anik and Vernal increased significantly between 2001 and 2005 (Fig. 1b). Total N increased by 0.47 Mg N ha^{-1} under Anik and 0.32 Mg N ha^{-1} under Vernal. Numerically, TN increased by 0.23 and 0.20 Mg N ha^{-1} under Yellowhead and the non-alfalfa control, respectively.

Discussion

Increased SOC and TN within transplanted alfalfa treatments may be explained by increased biomass productivity relative to the non-alfalfa control. Hendrickson et al. (2008) found significantly greater total biomass yield from the alfalfa treatments compared with the non-alfalfa control in 2 of 3 yr. Though root biomass was not measured, an increase in lateral roots in near-surface soil horizons from alfalfa would be expected to increase C and N inputs to the soil. Furthermore, fibrous root density from alfalfa is greatest in the surface 0.1 m of soil (Rechel et al. 1990), where SOC and TN responded to alfalfa treatments in this study.

While biomass contributions may help explain increased SOC and TN under transplanted alfalfa relative to the non-alfalfa control, interpretation of SOC and TN change between 2001 and 2005 within each alfalfa treatment is less apparent. Between the initial and final sampling, significant increases in SOC and TN were most under Anik, a grazing-type alfalfa, followed by Vernal, a hay-type alfalfa. These findings run counter to observed trends in biomass productivity among alfalfa cultivars, as Yellowhead (where changes in SOC and TN stocks were not significant) was the highest-yielding cultivar among those evaluated by Hendrickson et al. (2008). Between grazing-type alfafas, it is possible Anik contributed more C and N inputs to the soil through roots and rhizodeposits than

Yellowhead. The increase in SOC and TN stocks under Vernal may also be explained by below-ground inputs, as Vernal has been found to possess root morphology similar to grazing-type alfalfas, with more and larger lateral roots and abundant fibrous root mass (Johnson et al. 1998). Accordingly, our results suggest increases in SOC and TN under alfalfa within native rangeland are not necessarily limited to grazing-type cultivars.

It is important to acknowledge that conditions at the experimental site may have been primed for SOC and TN accrual. Soil organic C was 18% (14.4 Mg C ha^{-1}) less in the surface 0.3 m of the sampled treatments compared with a nearby (<0.5 km) native vegetation pasture grazed at 2.6 ha $steer^{-1}$ sampled in 2003 (Liebig et al. 2010). Lower initial SOC under the sampled treatments relative to the nearby grazed native vegetation pasture suggests a greater capacity to increase SOC with improved management in the former. Even so, SOC accrual rates under transplanted alfalfa were much lower than that observed by Mortenson et al. (2004), where the mean C sequestration rate was 1.56 Mg C ha^{-1} yr^{-1} after 4 yr.

Increased soil C storage under mixed-grass prairie without alfalfa has been documented (Frank 2004), so numerical increases in SOC and TN under the non-alfalfa control were certainly possible within the time-frame of this study. Consequently, SOC and TN accrual under the alfalfa treatments should be interpreted cautiously by taking into consideration the additive effects of native vegetation on SOC and TN observed under the non-alfalfa control.

The authors thank Mary Kay Tokach for establishment and maintenance of research plots, Jason Gross for assistance with sample collection, and David Brandt, Stephanie Eckroth, Gail Sage, and Becky Wald for sample processing and analyses.

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